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5.— The Reaction of Plants to Growth Regulators with particular reference to Weed Control

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The discovery, functions and composition of plant hormones are reviewed, along with the morphological and physiological responses of plants to related chemicals. The use of these chemicals in agriculture, particularly for weed control, is discussed and the results of work on weed and crop reaction in Western Australia outlined.

Introduction

About a century ago Julius Sachs deduced from his experiments on plants that special substances are responsible for the formation and growth of different organs. Sixty years later Fitting (1909) made the first efforts to determine the chemical nature of plant growth stimulators after finding that water extracts of dead pollen initiated swelling of the ovaries of orchids. He made several attempts to fractionate the pollen extract but no further advance was made until Laibach (1933) showed that the active pollen substance was probably identical with one of the auxins.

Over the same period discoveries were being made in another field of plant physiology dealing with tropisms. Darwin (1880) showed that some influence is transmitted from the upper to the lower part of seedlings when they are exposed to one sided illumination. Boysen-Jensen (1913) demonstrated that this stimulus can be transmitted through a gelatin layer by cutting off the tips of *Avena* coleoptiles and pasting them on again with gelatin. Six years later Paal (1919) showed that the stimulus did not cross a layer of cocoa butter, mica or platinum foil and that a tip placed on one side of the coleoptile caused curvatures similar to those seen in phototropic experiments. He postulated the existence of a diffusible correlation carrier which is produced in the tip and moves downward. Phototropic effects were explained by an interruption in the normal flow of the substance through interference with its action due to some change in the protoplasm.

Went (1926) was the first to collect the active material when he found that it diffused into gelatin from living oat coleoptile tips. This made possible the development of a technique for the quantitative measurement of the growth substance before it had been isolated chemically. An agar block containing the active material is placed on one side of the cut coleoptile surface after removing the tip and the amount of curvature caused by the growth difference of the two sides is measured. Up to a certain concentration the curvatures are proportional to the amount of growth substance applied. This *Avena* test has a high degree of sensitivity, one twenty millionth of a milligramme of growth substance giving a curvature of about 10 degrees.

Went's test was of considerable assistance to workers endeavouring to isolate and define growth substances. In 1928 Nielsen found that two pathogenic fungi produced in the nutrient medium, substances which were strongly active to the *Avena* test and shortly afterwards auxin production was associated with other fungi and bacteria. Attempts to isolate these substances were deferred when the *Avena* coleoptile was found to react strongly to urine. By 1934 three active substances had been isolated—auxin-a, auxin-b and 3-indolylacetic acid. The latter acid was subsequently isolated from yeast and *Rhizopus* and for some time was considered to be restricted to lower organisms. Evidence to the contrary, however, continued to increase and it was finally isolated from wheat and maize by several workers.

Use of Growth Regulators

Following the synthesis of growth regulating substances, applied experimental work was undertaken in a number of directions and plants were found to react in a variety of ways. One of the first practical uses was associated with vegetative propagation. With many plants that are difficult to strike, root development may be hastened and increased by treating the cuttings with growth regulating substances. These

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chemicals are being used by nurserymen without a great deal being known concerning their physiological action.

The theory that a natural root inducing factor moves from the leaves to the base of the cutting causing root initiation has been favoured for some time. When, for some reason this factor does not operate it is possible for it to be replaced by a synthetic growth regulator. Among the better known root inducing substances are indolylbutyric acid, naphthylacetic acid and naphthylacetamide.

Treatment of flowers such as those of the tomato, has under certain conditions, prolonged development resulting in larger fruits which may be seedless. With beans, maturation has been hastened and at the same time the size increased. The rate of ripening of formed fruits can also be hastened and it is not necessary for them to remain attached to the trees. Apples, pears, peaches and bananas have been stimulated by very small quantities —a few parts per million—of naphthylacetic acid and related chemicals.

An accepted practice to improve the fruit set of the Zante currant is to cincture or girdle the main stem of the vine, removing a narrow strip of the inner bark. It is thought that this restricts the downward movement of soluble food materials and results in a concentration above the cincture. The currant fruit is normally seedless and apparently this stimulus is needed to induce satisfactory fruit set and fruit size. With cincturing of weaker vines a marked deterioration of vigour may occur and an alternative method of improving fruit set has been sought. Work undertaken by L. T. Jones (1953) in the Swan Valley has shown that satisfactory setting has followed spraying with a solution containing 20 to 40 parts per million of *p*-chlorophenoxyacetic acid. 2, 4-dichlorophenoxyacetic acid was somewhat less effective and, at times, caused damage to the bunches.

Abscission of flowers has been both retarded and accelerated by the same growth regulator. The reaction of greenhouse tomatoes, however, has been sufficiently uniform for them to be treated commercially to prevent flowers from falling and these substances have also been used to replace pollination. Careful control of the treatment is essential as relatively small quantities are lethal to tomatoes.

Spraying to bring about thinning when excessive flowering of fruit trees occurs, takes advantage of the conditions when floral abscission is increased. The same variation occurs with leaves and fruits but detailed investigations have allowed growth regulators to be used in some cases for retarding fruit drop, a practical application that can be very useful in orchards. The stage of fruit development at the time of application is important.

Although the properties of growth regulating substances already mentioned are important, their herbicidal effects are of outstanding significance. The major portion of the address will be devoted to this aspect.

Herbicides

Chemistry

It is now generally recognised that indolylacetic acid is one of the important hormones found in plants and as it can also be synthesized in the laboratory, it has been an important starting point for the preparation of substances likely to have herbicidal properties.

Studies began at the Jealotts Hill Research Station, England, in 1936, the earliest work dealing with stimulation of the rooting of cuttings. It was soon extended to include the effects of 3-indolylacetic acid and 1-naphthylacetic acid at different concentrations upon seed germination, seedling development and the growth of established plants of many species. The results of these experiments showed that the higher concentrations of growth substances actually depressed growth. These observations together with a knowledge of the variation in root formation and deformation effects produced with different species led to the assumption that these growth substances in higher concentrations would have selective phytocidal action.

Slade, Templeman and Sexton (1945) found in 1940 that applications of 25lbs. naphthylacetic acid per acre to oats weedy with charlock (*Brassica sinapis*) killed the charlock. The oats received only a slight check and recovered fully. 84% of the charlock failed to germinate and seedlings that emerged soon died. Other experiments indicated that wheat, barley and rye behaved similarly to oats while large plantain (*Plantago major*) and yarrow or milfoil (*Achillea millefolium*) resembled charlock in their responses.

These results confirmed the selective phytocidal properties of certain growth substances and initiated the search for cheaper and more active chemicals than naphthylacetic acid. Within two years of this work investigators in both England and America had recognised the strong growth regulatory and herbicidal effects of chlorinated phenoxyacetic acids.

Even during the early investigations a considerable number of chemicals were screened. In America the derivatives of 2, 4-dichlorophenoxyacetic acid (2, 4-D) were favoured while in England, where exploratory work commenced several years earlier, the compound selected for development was 2-methyl-4-chlorophenoxyacetic acid (M.C.P.A.). This was due in part at least to the greater availability in England of chloro-cresol as opposed to chloro-phenol. Of the many other related chemicals that have been tried 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) has proved of greatest practical value forming the basis of preparations for treating woody plants.

It is interesting to note the similarity in the structural formula of indolylacetic acid and the synthetic hormone-like substances such as the chlorinated phenoxyacetic acids. The main difference in structure is that the $-CH_2COOH$ group of indolylacetic acid is attached to the benzene ring through a pyrrole ring while with the chlorinated phenoxyacetic acids this group is attached through an oxygen atom.

2,4-D acid is only slightly soluble in water and for herbicidal purposes its derivatives are the important chemicals. The most widely used are the sodium and triethanolamine salts and the esters. The sodium salt is moderately soluble in water but "hard water" having a high calcium or magnesium content may cause a precipitate that will clog the filters and spraying nozzles. The amine salts are soluble in all proportions in water and are therefore well adapted to the low volume spraying equipment. even when high rates of chemical are required. The ester compounds are only slightly soluble in water but may be dissolved in some petroleum oils. By the use of suitable emulsifiers the minute oil droplets containing the ester can be kept in suspension in a suitable form for spraying purposes. The esters are synthesized by the reaction between 2,4-D acid and an alcohol. As a large range of alcohols is available it is potentially possible to have a large range of 2,4-D esters, although naturally the cheaper and more readily available alcohols are mainly used. e.g., methyl. ethyl. isopropyl and butyl. The length and structure of the alcohol portion of the 2,4-D ester molecule affects its vapour pressure and in consequence, the volatility. In general, the longer the carbon chain in the part of the molecule contributed by the alcohol the lower the volatility. Where low volatility is important, high molecular weight alcohols have been used but they are more expensive. M.C.P.A. has been used mainly as the sodium salt and has similar properties to 2,4-D. With 2,4,5-T, the ester is the main formulation, in some cases high molecular weight alcohols being used to reduce volatility.

As the components of proprietary lines of herbicides have different molecular weights and are also prepared in different concentrations it is essential to be able to compare the active chemical content of preparations and to have a uniform method of expressing rates of application. The term acid equivalent is used and refers to that part of a 2,4-D formulation that theoretically could be converted to the acid. The acid equivalent may be stated as a percentage by weight or the weight of 2,4-D acid in a given volume.

2,4-D may be classed as a non-toxic substance. Cows and sheep were not affected by feeding on pasture sprayed with 2,4-D and no harmful results followed daily doses of 5.5 grams to a cow for 106 days. The 2,4-D was not excreted in the milk, nor was it found in the blood serum of a calf given milk from the test cow. There is some evidence that the growth of aerobic micro-organisms may be inhibited while some groups of anaerobic organisms may be stimulated. At the usual rates of application 2,4-D does not generally reduce the total number in the soil.

Morphological Effects

The effect on plants depends primarily on the quantity applied and absorbed but is also influenced by a number of other factors including the growth stage of the plant, the rate of growth at the time of spraying and climatic conditions, particularly temperature. As already mentioned, at controlled rates, the growth regulating properties are apparent at much lower concentrations than the toxic effects. The first reaction is often a twisting or bending of the stems and leaves resulting from differential growth rates in petioles and elongating regions of the stem. Leaves may become thickened and an increase in turgor often results in a propping appearance. Colour changes similar to autumn leaves may occur. Stems also become thickened and often split. The extreme response is a cessation of growth followed by a characteristic browning of the foliage and stems associated with the dying of the tissue.

With sublethal doses the reaction of the plant takes a number of forms. Besides the twisting of the stems already mentioned, leaves produced after the application may assume unusual shapes. Entire leaves become deeply divided and those normally having broad lobes may be reduced to narrow segments. Proliferation of floral parts is not uncommon and fasciations are also caused as well as adventitious roots. Parthenocarpy may be induced resulting in seedless fruits. In the case of cereals. irregular spikelets and empty florets occur. These responses can be attributed to the interference of hormonal action in the young structures by the synthetic growth regulating substances. 2,4-D appears to concentrate in the young embryonic or meristematic tissues that are in a rapid state of metabolic activity, affecting them more than mature or relatively inactive young tissues.

Physiological Effects

Although the physiology underlying the effects of synthetic growth substances on plants is far from being fully understood and applied studies have been given more attention than fundamental research, part of the story can be told. The severe and diversified effects indicate that they exert an influence on some general and basic metabolic process. As pointed out by Bonner and Bandurski (1952), according to this view, the observed response, whether growth by elongation, production of roots, suppression of lateral buds or of flowering, increase in rate of protoplasmic streaming or production of changes in chemical composition, would be the visible manifestation of the effects on this common basic process. A ready and simple explanation would be an essential relationship between enzymes and growth regulating substances. It has been shown that the action of numerous enzymes are influenced by these substances, some being increased and others inhibited, but information available gives only partial support to this theory.

A number of effects on chemical composition and physiological processes have been recorded. Respiration may be stimulated or retarded, the reaction apparently depending on the concentration in relation to the susceptibility of the plant. Kelly *et al.* (1949) showed that the rate of respiration in pea seedlings was increased by concentrations within the range of 0.001 to more than 100 parts per million of 2,4-D while 1,000 parts per million reduced the rate by 40 per cent. On the other hand a 20 per cent. stimulation with oat seedlings required at least

1,000 times as much 2,4-D as for the same stimulation in pea seedlings. Even when lethal doses are applied an initial increase in respiration may occur followed by a reduction as the plant approaches death. The influence on the respiration rate is considered by some workers to be linked with the effect of 2,4-D on water uptake.

By some means not fully understood 2,4-D upsets the balance between synthesis and use of plant food, particularly carbohydrates. After application in herbicidal quantities there is a slight decrease in the rate of photosynthesis associated with a steady loss in total dry weight due mainly to a decline in the weight of starch and starch-like substances. Usually there is an initial increase in the sugars followed by a rapid and steady decline. There is still some doubt whether the depletion of sugars is sufficient to cause death of the plant.

Both increases and decreases in the protein content of wheat grain have been recorded with increases predominating. When higher percentages have been recorded some doubt has existed whether there was increased synthesis of the proteins or whether a decrease in total seed weight accounted for the proportional increase. There are indications of a lowering of the nitrogen and potassium absorption and treatment with 2,4-D has also reduced the upward movement of radioactive phosphorus to the leaves and modified the distribution and accumulation pattern of this radical.

It has been proposed by van Overbeek (1947) that 2,4-D, like natural auxin, might affect oxidative assimilation in the cell but unlike auxins might escape inactivation by oxidases that normally regulate metabolism. The resultant increase in the catabolic processes in the cells while the anabolic system was blocked would cause rapid injury to the plant. Johnson and Fults (1952) have shown that once it has entered cells, 2,4-D stimulates the production of scopoletin, a coumarin-like compound that is highly toxic.

Although the actual cause of plant mortality following the application of growth regulating substances has not been defined with certainty there is no doubt that they disorganise a number of metabolic processes.

Absorption and Transloeation

It is already apparent that growth regulating substances applied to plants produce effects at some distance from the point of application. This involves both absorption and translocation. Hormones may be transported in plants by three different mechanisms. Following absorption by the roots they move in the xylem transpiration stream to the leaves. In the process they may be absorbed selectively and accumulated in adjacent active tissue such as xylem, parenchyma and cambium. Hormone molecules in leaves move with carbohydrates into the phloem where they are carried in the assimilation stream to regions where foods are being used or stored. In living parenchyma hormones may move from cell to cell by a polar mechanism.

Researches undertaken by many independent workers indicate a decided similarity between the movement of plant hormones and 2,4-D substances. It is generally accepted that chemicals in aqueous solution do not enter the leaf through the stomata but diffuse through the cuticle. Crafts (1948) suggested that, for ready entry through the cuticle, herbicides should be in a non-polar form. This would explain why the non-polar esters of 2,4-D pass through a waxy cuticle more rapidly than the polar salts.

Having penetrated the cuticle the 2,4-D molecules pass from a lipoidal medium into the aqueous medium of the mesophyll cells where somewhat polar properties are required to facilitate translocation. Experiments undertaken by Crafts (1952) have shown that 2,4-D ions of the sodium salt enter leaves slowly; aliphatic esters enter rapidly but do not part from the cuticle and translocate well; and 2,4-D acid and heavy ester molecules pass through cutiele, mesophyll and phloem with relative ease. Having reached the phloem without causing immediate damage to the intervening tissue they are translocated with synthesized food materials to regions where it is being used. The affects of the 2,4-D are therefore likely to be felt at the most vital points and deep penetration of perennial rooting systems is often possible.

Translocation can be quite rapid. Although one to two hours may be required for the chemical to penetrate the cuticle and move across the mesophyll, Day (1950) has shown that in the phloem it may move at rates from 20 to 160 cm. per hour. The rate of movement is not related to concentration of 2,4-D but is influenced by the rate of food movements. High concentrations can impede or arrest translocation by acting as contact herbicides and killing the conducting tissue.

Differential Action

For the agriculturist the most important characteristic of synthetic growth regulators is their selective action on plants. Although in general, grasses are resistant and broad leaved dicotyledons are susceptible there are many exceptions involving variation in tolerance of different species and even different varieties. Undoubtedly a number of factors contribute to the variation in reaction.

A waxy cuticle, particularly when associated with close parallel venation as with cereals, causes many spray droplets to bounce and run off. On the other hand broad leaved plants have leaf surfaces that are more readily wet by sprays which may spread as a thin film or retain contact over a large proportion of the surface in the form of fine droplets. The upright habit of grasses, especially cereals, also causes more run off than leaves that are disposed in a more or less horizontal position. Again, in the case of grasses the growing points are located in the crown of the plant, at or below soil level and are therefore protected by foliage. With broad leaved weeds the growing points at the tips of the shoots and in the leaf axils are usually exposed.

Selective action may also be influenced by factors affecting absorption and translocation. Reference has been made to the fact that these processes are affected by the relative polarity of the chemical and the tissue. Absorption of polar substances through the roots is uninhibited but there may be some selectivity due to restriction of entry through heavily cutinised cuticles. Variation in translocation which is closely linked with the plant species and stage of growth can also result in differential reaction.

Although morphological characteristics contribute, the main causes of differential action are associated with physiological differences. The story is only partially understood, however, and factors such as differences in enzyme systems, response to pH changes, chemical constitution of the plant and cell metabolism, may be involved. These factors are affected by the age of the plant and also by environmental conditions, such as temperature and available moisture. When physiological processes are slowed down by such factors, reaction to 2,4-D is usually less apparent. There is some systematic correlation between synthetic hormones and plants, e.g., members of the Cruciferae are, in the main, susceptible, while the Polygonaceae which includes many broad leaved types such as docks (*Rumex* spp.) and doublegee (*Emex australis*) are relatively resistant. The correlation does not extend very far, however, as responses have varied with different species and even different varieties of the one species.

Agricultural Application

Although employed primarily as selective herbicides, 2,4-D and related compounds can be used as contact sprays for killing annual and checking perennial weeds, as translocated sprays, particularly for perennials and as temporary soil sterilants. Our main interest, however, is in the selective control of annual weeds in cereal crops. It is proposed to deal with the various factors involved in relation to development and research in Western Australia.

Two of the most widespread and troublesome weeds in this State are wild turnip (*Brassica tournefortii*) and wild radish (*Raphanus raphanistrum*). As these are both annual species of the Cruciferae and are closely related to *Brassica sinapis* with which some of the original experiments were undertaken at Jeallots Hill, trials with them were commenced as soon as the chemicals became available. Much of the subsequent work has been done with these two plants along with doublegee (*Emex australis*).

Type and Quantity of Chemical

The first commercial lines were the sodium salts of M.C.P.A. and 2,4-D. These were soon followed by the triethanolamine salt and various esters of 2,4-D and latterly corresponding compounds of M.C.P.A. have also been formulated. The earlier overseas reports frequently referred to application rates exceeding one pound of acid equivalent per acre. With high average yields of forty bushels or more per acre the cost of such treatments could be absorbed but such rates were difficult to reconcile with the relatively low cereal yields in this State. Meadly (1951) recorded effective control of young wild turnip plants in a cereal crop at Wongan Hills with both two and four ounces acid equivalent per acre, the species being particularly susceptible. Treatment increased the yield of a heavily infested crop on light land from 8.5 bushels to 13.2 bushels per acre. Corresponding yields at Dalwallinu were 5.7 and 11.6 bushels respectively. Other formulations have since been proved effective and four ounces acid equivalent per acre is used for most spraying of wild turnip although, when conditions are favourable, somewhat lower rates have been equally satisfactory.

The story with wild radish has been somewhat different. With the initial trials, using the sodium salts, four ounces acid equivalent per acre checked the plants but a proportion recovered and set seed. Much more satisfactory control was obtained at the eight ounce per acre rate. In the years immediately following, wild radish spraying was undertaken with the amine and sodium salt of 2,4-D and the sodium salt of M.C.P.A. mostly at four ounces of acid equivalent per acre but sometimes at six. During this period a number of indifferent results caused concern among farmers. The reason for some, but by no means all of these could be traced and further detailed investigations were undertaken (Meadly 1954). Chemicals used were the sodium salt of M.C.P.A. and the amine, ethyl ester and butoxyethanol ester of 2,4-D. All were applied at both four and six ounces of acid equivalent in five gallons of water per acre. The four ounces of M.C.P.A. and 2,4-D amine affected a proportion of the wild radish plants but did not give a satisfactory degree of control. The six ounce rate of both gave practical control although some plants recovered and set seed. There was no difference between the two types of ester but the results with four ounces of acid equivalent per acre were somewhat better than those with six ounces of amine and M.C.P.A. The six ounce rate of both esters gave complete control of wild radish. Based on this work the ester is now being used largely by farmers for this weed with increased uniformity of results. It is not usually recommended, however, when the cereal is undersown with a legume and this aspect of crop tolerance will be discussed later.

The habit of doublegee and the fact that it is an annual gave reason to believe that it would be susceptible to moderate rates of application of 2,4-D. This plant has belied its appearance, however, and much research over a period of years has failed to provide a really effective treatment. Meadly and Pearce (1954, 1955) record trials with various formulations of 2,4-D at a wide range of acid equivalent levels. Results were variable and no treatment could be relied upon to give a high degree of control. With heavily infested crops six ounces acid equivalent of 2,4-D ester per acre has suppressed the growth of young doublegees sufficiently to warrant its application but has not prevented seed formation. A second treatment two weeks after the first, even with the lower rates, gave a total kill of doublegees in one trial at Geraldton in 1954, but the same double treatment at Beverley was not effective.

Volume of Application

When hormone-like chemicals were first applied for weed control the volumes used for other herbicides were followed and one hundred gallons or more of solution were applied per acre. Such volumes, although inconvenient, are acceptable for highly productive crops but would present a problem under the conditions applying in this State where large areas require treatment and suitable water is not always readily available. It is simple mathematics to compute that 500 acres, by no means an excessive area for one property, would require 50,000 gallons of water if sprayed at the rate of 100 gallons per acre. This quantity must not only be supplied but transported to the site of operations.

The agriculturist and engineer soon joined forces and overcame this major difficulty by constructing nozzles which, when fitted to booms were capable of an even and effective application with as little as four or five gallons per acre. Later developments include nozzles having spinning discs and rotating brushes and also various types of atomisers. Most of the cereal crop spraying in Western Australia is now being undertaken with six to eight gallons per acre, using booms of 30 feet or more in length and travelling at about four miles per hour. An average coverage is 15 acres per hour.

A more recent development is the application of 2, 4-D by means of aircraft. With Tiger Moths, the main type in use in this State, the tank capacity is approximately 30 gallons and therefore the rate used with low-volume booms is scarcely practicable, as it would entail landing and refilling after four or five acres of spraying. A specially designed nozzle, however, has made possible a satisfactory application of two gallons per acre enabling 15 acres to be treated with each flight. Much work has been involved in calibrating aircraft, including determining the effective spraying swathe and ensuring an even dispersal of an adequate number of spray droplets.

Droplet Size

When considering droplet size two important factors are involved. The spray must be in such a form that it actually reaches the plant under average conditions of wind, temperature and humidity and upon making contact permits absorption of the chemical by the plant. Fisher *et al.* (1952) reported that coarse droplets estimated to be 450-500 microns gave somewhat higher kills of mesquite *(Prosopis juliflora)* than either fine or medium-coarse droplets, both of which gave comparable results. Other workers, however, including Mullison (1953) consider that the herbicidal effect is controlled by the amount of 2,4-D applied rather than the number or size of the droplets. All are agreed that the droplet size must be such that it does not evaporate or be dispersed by wind between boom and weed.

The amount of potential drift depends on wind velocity and droplet size. A still atmosphere is the ideal but in practice it is necessary to operate with a low velocity wind. With ground machines the effect can be minimised by having the boom as near the target as possible. In order to obtain complete coverage, however, the distance is seldom less than one foot and with some nozzles may be two feet. With aircraft operating in Western Australia the boom is usually six to ten feet above the crop. Maximum wind velocities suggested are 12 miles per hour for ground machines and seven to eight miles per hour for aircraft.

An interesting chart published by Edwards and Ripper (1953) shows the relation between droplet size and distance of drift under different conditions. Droplets having a mass medium diameter of 50 microns while settling 10 feet will drift 500 feet in a 10 m.p.h. breeze, and 200 feet in a 3 m.p.h. breeze. The corresponding figures for droplets having a m.m.d. of 400 microns were 30 feet and less than 10 feet. The need for a large droplet size with aircraft application is obvious but the m.m.d. is limited by the economic application rate and the likelihood of missing some of the weeds if the figure is too high. With aerial spraying the tendency is to produce coarse droplets with m.m.d. about 300-450 microns while with low volume ground units the figure usually varies from 90-120 microns.

Growth Stage of Plant

Plants, in general, are most vulnerable to hormone-like substances when at the seedling stage. Later, reaction may be closely correlated with the rate of growth. Plants checked by adverse conditions such as low temperatures and lack of moisture tend to be more resistant and difficult to kill. This would appear to be due to the greater susceptibility of active meristematic tissue.

The greatest benefit to cereal yields can also be expected from early removal of weed competition. It is necessary to ensure, however, that a more or less complete emergence of the target weed has occurred before spraying and also that the crop is at a tolerant growth stage.

Weather Conditions

As already discussed, strong winds are very undesirable as they accentuate spray drift, particularly with aircraft application. An additional hazard to nearby susceptible crops is presented by nozzle drooling when ferrying or turning near them. This has been reduced by the use of individual cutouts on each boom nozzle, at times supplemented by suction by means of a Venturi device when the main valve is closed. In America the use of volatile esters is not favoured because of the risk of damaging susceptible crops, particularly cotton. In Western Australia, however, cases of injury to crops such as tomatoes and lupins have occurred with the relatively low-volatile preparations and have been due to drift during operations rather than subsequent volatilisation and movement. In America, with aircraft spraying, some particles have been carried by air currents for distances up to four miles while in this State lupins more than one mile away from spraying operations have been damaged severely.

The most adverse combination for aerial spraying is a high wind velocity and temperature associated with low humidity. Besides the drift factor, significant evaporation of droplets can take place during passage from the boom to the herbage. On the other hand higher temperatures favour growth and tend to make the weeds more susceptible to the chemical.

During the winter, mild conditions are more likely to favour than detract from results. Although fine weather is recommended, rain a few hours after treatment, particularly when using 2,4-D ester, is unlikely to affect results.

Tolerance of Crops

Although the selective action of the synthetic hormone-like substances is one of their outstanding characteristics, reference has already been made to the high susceptibility of certain crops and there is by no means complete tolerance in the case of many sprayed extensively for weed control. In this State we are concerned mainly with cereals and a considerable amount of research has been undertaken, to define a safe level of treatment. Although there is some variation in the results reported it is possible to make conclusions of practical value.

Cereals are likely to be affected if sprayed at the seedling stage but develop resistance when tillering or stooling has progressed. Treatment during this early danger period can result in a number of malformations and growth disturbances. Wheat may develop club shaped, twisted and branched ears with an irregular arrangement of spikelets. The glumes may become fused, the number of spikelets in each group reduced and a proportion of the florets aborted. Symptoms also include thickened culms, chlorosis, reduction in height and delayed maturity.

Susceptibility again increases at the "boot" stage when the head is enclosed in the leaf sheath. Risk of damage continues during pollination but decreases at the "milk" and soft dough stages. Late spraying does not usually cause abnormalities but reduced grain setting has been attributed to it. Workers are in general agreement that wheat is least and oats most susceptible with barley occupying an intermediate position. There is also variation in reaction to formulations. The ester of 2,4-D is likely to be most severe, with the sodium salt of M.C.P.A. least harmful.

During 1954, at the Merredin Research Station three wheat varieties—Bungulla, Bencubbin and Wongoondy—were sprayed at the pretillering, early tillering and "boot" stages with eight ounces acid equivalent per acre of 2,4-D amine, 2,4-D ester and sodium M.C.P.A. Yields of grain showed no significant difference due to variety or growth stage although there were indications of reduced yields with the pretillering and "boot" stage treatments. This tendency was more noticeable following the later spraying. With research in other countries cereal damage is usually associated with application rates of one pound or more of acid equivalent per acre. Eight ounces were used in the Merredin trial as higher rates are seldom applied for weed control in cereal crops in Western Australia. There is little doubt that external factors including climatic and soil conditions, by virtue of their influence on the growth processes of cereals can influence results. Some abnormalities have followed field spraying at four ounces acid equivalent per acre of 2,4-D amine but only a small proportion of the plants have been affected.

In a country so dependent on subterranean clover (*Trifolium subterraneum*) as a legume it is important that information should be available concerning its reaction to the various formulations, especially when first sown along with a cereal. Although a considerable amount of work on clover tolerance has been published little of it has dealt specifically with subterranean clover and the results show a decided difference in reaction between species. Again most of the investigations have been undertaken with pastures where clovers tend to be more resistant than when growing in association with a cereal crop.

Some exploratory work undertaken in 1952 on a pasture dominated by the Dwalganup strain of subterranean clover indicated that this species, except at the small seedling stage, is not readily killed by application of 2,4-D, many plants persisting at the 2 lb. per acre acid equivalent rate of M.C.P.A. and 1½ lb. per acre acid equivalent rate of 2,4-D amine. It was apparent, however, that even some of the lighter treatments retarded the date of flowering. This could be vital in districts having a short growing season as it would be equivalent to converting Dwalganup into a later strain from a maturity viewpoint and might prevent effective seed setting. Any reaction of this nature would be of greatest significance in the case of spraying to control weeds in the year of clover establishment. Few, if any, dormant seeds would be present in the soil and regeneration of the clover could only be obtained from seed formed in the season of sowing. As subterranean clover is frequently established along with a cereal crop which would normally be sprayed for weed control the reaction of the clover to chemicals under such conditions is most important.

An experiment was designed to ascertain the effects on seed setting of different formulations applied at various rates to Dwalganup subterranean clover sown along with a crop. It was intended to carry out the experiment at a number of different centres but conditions during 1954 restricted the work to one property in the Toodyay district on land being cropped for the first time. The clover was sown at 8 pounds per acre with a light cover crop of wheat.

The sodium salt of M.C.P.A. and the amine salt and ethyl ester of 2,4-D were applied to the various plots as shown in the table. The required amount of chemical was dissolved in water and applied at 5 gallons per acre through a low-volume boom. At the time of spraying the crop was approximately 9 inches tall and stooling freely while the clover was at the 3 to 4 leaf stage. In order to estimate the effects of the treatment 12 plant counts of one square link were made on each plot. The position of each count was marked and at the end of the season the seed was removed from the individual areas. In this way the seed set by over 2,500 plants was recorded.

Table Showing Seed Formation.

Treatment	Ozs. acid equivalent per acre	No. of seeds set per plant
M.C.P.A. (sodium salt)	4	6.6
,, ...	8	8.5
,, ...	12	7.0
,, ...	16	7.4
,, ...	24	3.2
,, ...	32	4.9
2,4-D/amine (triethanolamine) ..	4	5.7
,, ...	8	4.3
,, ...	12	2.1
,, ...	16	1.0
,, ...	24	0.8
,, ...	32	0.6
2,4-D/ester (ethyl)	4	3.1
,, ...	8	3.0
,, ...	12	1.4
,, ...	16	0.9
,, ...	24	1.1
,, ...	32	1.0
Control	—	8.7

Significant difference between treatments (P=0.05) = 3.35.

The results are summarised in the table and illustrated by the graph. With M.C.P.A. the yield of seed per plant was significantly depressed for all treatments above the 16oz. level. In the case of 2,4-D amine the depression occurred with all treatments above the 4oz. level, while with 2,4-D ester all treatments caused a significant reduction in seed yield.

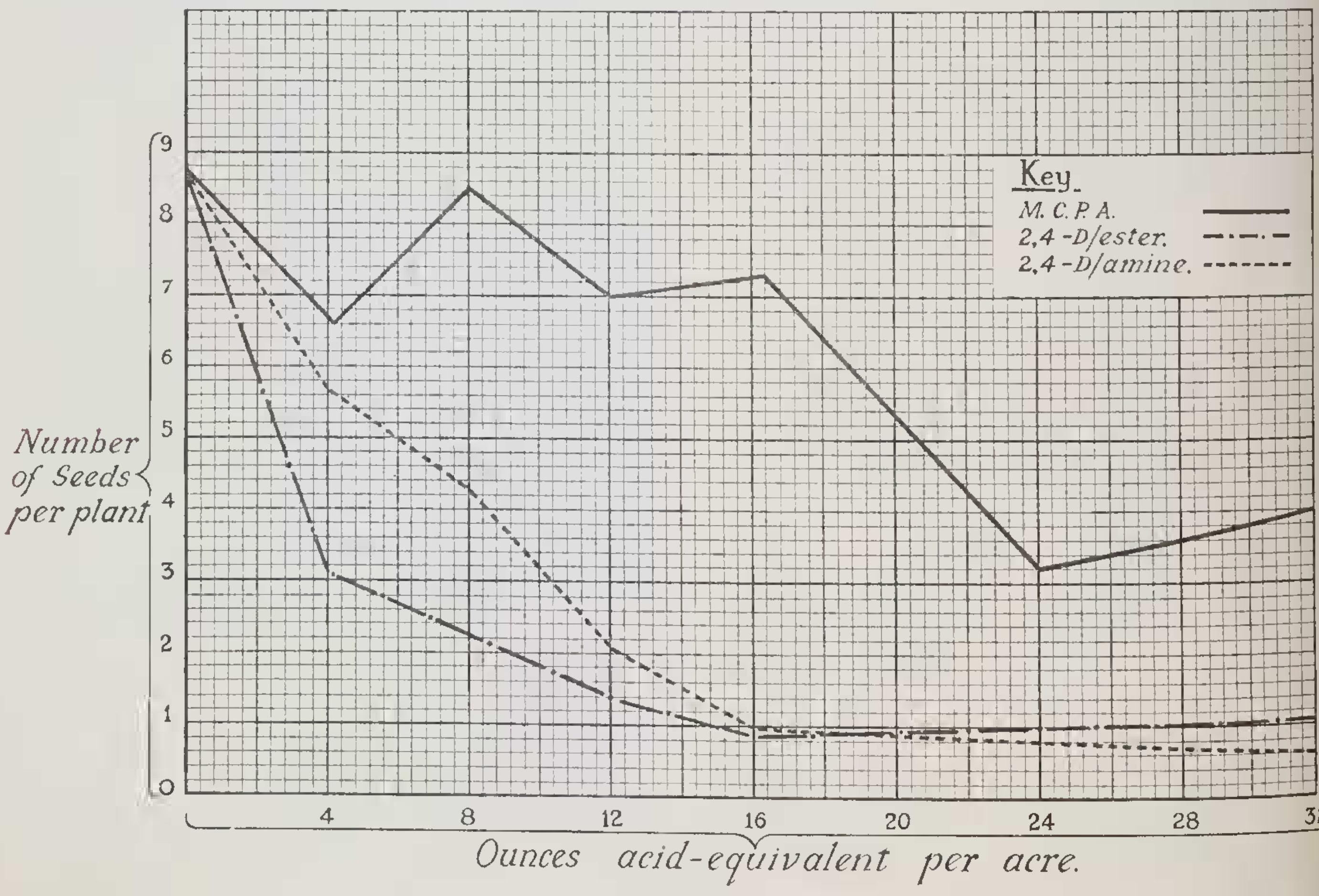
The results have considerable practical value and have made possible tentative recommendations regarding the spraying of cereal crops with undersown clovers (Meadly and Pearce 1955). Further similar trials during 1955 at four different centres should complete the information required and allow details regarding formulations and quantities to be defined.

Other Weeds

The growth regulators have proved very useful for the destruction of other weeds besides those controlled selectively in cereal crops. Cape tulip (*Homeria breyniana* and *H. miniata*) reacts to relatively high rates of application, corm and cormil development being arrested. The most effective formulation, optimum economic dosage and most vulnerable growth stage have been defined by Meadly (1954). The ester of 2,4-D has given best results and the most favourable time for spraying is somewhat later for *H. breyniana* than for *H. miniata*. A number of other troublesome herbaceous weeds are also susceptible.

Among woody plants blackberry (*Rubus fruticosus*) has been treated successfully with the ester of 2,4,5-T. No advantage has been gained by using a mixture with 2,4-D ester. Time of application is significant, treatment at the flowering and fruiting stage in mid-summer being most effective. This is assumed to correspond with active downward movement of food materials in the phloem facilitating translocation and deep penetration by the 2,4,5-T. Although foliage spraying of mesquite (*Prosopis juliflora*), including aerial applications, have not proved effective good results have followed treatment of the basal portion of the stump with a 1% acid equivalent solution of 2,4,5-T in distillate.

Some work has also been undertaken with York Road Poison (*Gastrolobium calycinum*) and regrowth of various *Eucalyptus* species. Results have been very variable and relatively high rates of application are necessary. This method of treatment is not economical for large, dense areas but may prove advantageous under



some conditions such as with poison plants growing in rocky situations where it is difficult to undertake other control measures. In some cases 2,4,5-T has proved more effective and no more costly than bashing for controlling *Eucalyptus* suckers. With *Gastrolobium* species best results have followed the application of 3-4 lb. acid equivalent in 150 gallons of water per acre of vegetation when the plants are flowering in the Spring. With eucalypts autumn treatment has proved more effective.

Conclusion

During the relatively short period that synthetic growth regulating chemicals have been available rapid and spectacular advances have been made. Extensive research has been undertaken in many countries with a natural tendency for the concentration to be on applied rather than fundamental aspects. The need for more basic physiological information is now being felt and this field is receiving more attention.

The use of these chemicals for weed control alone has resulted in enormous savings to the agricultural industry. Figures for Western Australia, although not on the same scale as those for Canada and the United States, underline this statement. In a period of three years the area sprayed for the control of weeds in cereals increased from experimental proportions to an estimated total of 400,000 acres in one season. Based on a conservative estimate of increase in yield due to treatment, the additional annual production approaches one million bushels. Experience in this State gives support to the statement of an eminent scientist that the discovery of the herbicidal properties of growth regulating substances is the greatest scientific contribution to agriculture since superphosphate fertilizer.

It is likely that further researches by the chemist and agriculturist will result in improved formulations that will increase the effectiveness of present work and extend the range of species that can be controlled chemically.

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